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Conformal composite acoustic transducer panel and method of fabrication thereof

### Abstract:

A conformable composite acoustic transducer panel including a conformable composite body having upper and lower planar faces and upper and lower thin, flexible electrodes bonded to the upper and lower faces, respectively. The composite body includes an array of individual piezoelectric or electrostrictive ceramic elements extending normal to the upper and lower faces and through the composite body from the upper face to the lower face to electrically contact the electrodes. Stiff integral face plates are bonded to the side surfaces of the elements at their upper and lower ends. Alternatively, a conformable, stiff, voided polymer matrix is bonded to the element sides over their entire length. Flexible circuit boards may be bonded to the electrodes to provide electrical contact thereto. Methods for fabricating the transducer panel are also disclosed.

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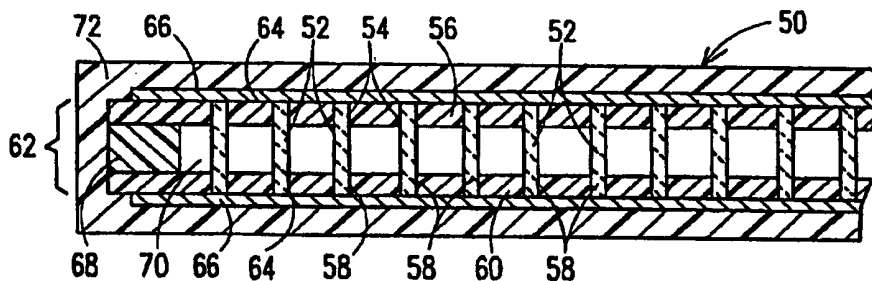
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(54) Title: CONFORMABLE COMPOSITE ACOUSTIC TRANSDUCER PANEL AND METHOD OF FABRICATION THEREOF



## (57) Abstract

A conformable composite acoustic transducer panel (50) including a conformable composite body (62) having upper and lower planar faces (64) and upper and lower thin, flexible electrodes (66) bonded to the upper and lower faces, respectively. The composite body includes an array of individual piezoelectric or electrostrictive ceramic elements (52) extending normal to the upper and lower faces and through the composite body from the upper face to the lower face to electrically contact the electrodes. Stiff integral face plates (56) are bonded to the side surfaces of the elements at their upper and lower ends (54, 58). Alternatively, a conformable, stiff, voided polymer matrix (34) is bonded to the sides of the elements (32) over their entire length. Flexible circuit boards (96) may be bonded to the electrodes (66) to provide electrical contact thereto. Methods for fabricating the transducer panel are also disclosed.

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CONFORMABLE COMPOSITE ACOUSTIC TRANSDUCER PANEL  
AND METHOD OF FABRICATION THEREOF

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BACKGROUND OF THE INVENTION

The present invention relates to electrically activated acoustic transducers and hydrostatic pressure sensors, and particularly relates to acoustic transducer panels fabricated as a composite of a piezoelectric or electrostrictive ceramic material and a polymeric material as well as methods for fabrication thereof.

The need for detection and control of vibration and noise have long been recognized in technical applications such as hydrophones, actuators, hydrodynamic flow control, hydrodynamic noise control, underwater sound suppression, and structural vibration control. Electromechanical transducers, especially piezoelectric ceramics and polymers, have been used for the interconversion of electrical and mechanical energy in such acoustic applications. Piezoelectric and electrostrictive ceramic/polymer composite materials have been identified as having significant potential for improving the performance of many acoustic transducer systems.

Two of the most important configurations developed for such a composite transducer are those exhibiting the so-called 1-3 and 2-2 connectivity described in detail in U.S. Patent No. 5,340,510, issued to Leslie J. Bowen, one of the inventors of the present application. (Patent 5,340,510 is incorporated herein by reference.) The 1-3 composite is a one-dimensionally connected piezoelectric or electrostrictive ceramic phase, e.g., an array of lead zirconate titanate (PZT) rods, pins, or fibers, contained within a three-dimensionally connected polymer phase. The 2-2 composite is made up of two-dimensionally connected ceramic, e.g., paral-

1el PZT strips, separated by two-dimensionally connected parallel polymer strips.

Presently, a thin stiff face plate, e.g., one fabricated from glass-fiber reinforced plastic (GRP) or metal, is bonded to the transducer panel as an end cap or cover plate for the ends of the rods to minimize in-plane motion of the transducer. In some situations, however, the introduction of such a stiffening face plate can lead to other concerns. For example, delamination of the device may occur during use, the device may be susceptible to damage from shock, or the device may not be sufficiently flexible or conformable to, e.g., non-planar mounting surfaces.

Especially desired for the hydrodynamic flow control, hydrodynamic noise control, underwater sound suppression, and structural vibration control applications described above, as well as other applications, has been a flexible, shape-conforming actuator panel configuration which can be applied over and conformed to a large surface area to detect and control vibration and noise over that area. Ideally, such an actuator panel should exhibit a very high actuator authority, provide a uniform surface response, be rugged and shock resistant, and be readily fabricated at relatively low cost. The composite acoustic transducer panels described herein were developed to address that need.

#### SUMMARY OF THE INVENTION

In some embodiments, the invention is a conformable composite acoustic transducer panel including a conformable composite body having upper and lower planar faces and upper and lower thin, flexible electrodes bonded to the upper and lower faces, respectively. The composite body includes an array of individual piezoelectric or electrostrictive ceramic elements, each of the elements having opposing ends, and one or more sides interconnecting the opposing ends. The

elements are disposed normal to the upper and lower faces and extend through the composite body from the upper face to the lower face to electrically contact each of the electrodes. The composite body also includes either a matrix of conformable, stiff, voided material or upper and lower integral face plates bonded to the sides of the elements.

In one of these embodiments, a matrix of conformable, stiff, voided material extends the full depth of the composite body and is bonded to each of the elements over the full length of each of the element sides. The voided material includes a hard polymeric material and about 1 - 50 volume percent voids. In this embodiment, upper and lower surfaces of the integral face plate are coplanar with upper and lower ends, respectively, of the elements to provide the upper and lower faces, respectively, of the composite body.

In an alternate embodiment, an upper integral face plate and a lower integral face plate are spaced apart from one another. Each of the integral face plates extends through only a portion of the depth of the composite body and is bonded to each of the elements over only a portion of each of the sides. The outer planar surfaces of the upper and lower integral face plates are coplanar with upper and lower ends, respectively, of the elements to provide the upper and lower planar faces, respectively, of the composite body.

In other embodiments, the invention is a method of fabricating a conformable composite acoustic transducer panel including a conformable composite body having upper and lower planar faces. The method involves placing in a mold a ceramic body having an array of individual piezoelectric or electrostrictive ceramic elements and, optionally a base. Each of the elements has opposing first and second ends and one or more sides interconnecting the first and second ends. The elements are disposed normal to the

base with the first ends fixed thereto. A polymer is disposed over the ceramic body within the mold to a depth sufficient to encapsulate the base and the elements to form an encapsulated ceramic body. The encapsulated ceramic body is machined, if necessary, to remove the base and expose the first and second element ends, producing the conformable composite ceramic body.

In one of these embodiments, the encapsulating polymer is a conformable, stiff, voided material including a hard polymeric material and about 1 - 5 volume percent voids. The voided polymeric material is disposed to extend the full depth of the composite body to form a matrix encapsulating the base and the elements to form the encapsulated ceramic body. The polymer bonds to each element over the full length of the element sides. The encapsulated composite body is machined, if necessary, as described above to produce the conformable composite ceramic body. Outer surfaces of the matrix provide the upper and lower planar faces of the conformable composite body.

In an alternate embodiment, a conformable composite acoustic transducer panel including a conformable composite body having upper and lower planar faces is fabricated. The method involves disposing a polymer over the ceramic body within the mold to a first depth encapsulating the base, if present, and a portion of the element sides adjacent the first element ends, leaving a portion of each of the element sides unencapsulated to form a partially encapsulated ceramic body. The polymer is selected to provide on curing a first stiff polymeric integral face plate bonded to the portion of the element sides adjacent the first element ends. The partially encapsulated ceramic body is inverted in the mold such that the base, if present, and the first integral face plate are supported in the mold by the unencapsulated portion of the elements. The polymer is disposed

over the inverted ceramic body within the mold to a second depth encapsulating a portion of each of the element sides adjacent the second element ends, leaving a portion of each of the element sides unencapsulated. On curing of the polymer an encapsulated ceramic body is formed having a first stiff polymeric integral face plate bonded to the portion of the element sides adjacent the first element ends, a second stiff polymeric integral face plate bonded to the portion of the element sides adjacent the second element ends, and a gap between the integral face plates. A stiff polymeric edge joining means may be applied to the encapsulated body to join the first and second integral face plates at their outer edges and enclose the gap. The encapsulated ceramic body is machined, if necessary, as described above, producing the conformable composite ceramic body. Outer surfaces of the first and second integral face plates provide the upper and lower planar faces of the conformable composite body.

#### BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, together with other objects, advantages, and capabilities thereof, reference is made to the following Description and appended Claims, together with the Drawing in which:

Figure 1 is a cross-sectional elevation view of an acoustic transducer panel in accordance with the prior art;

Figure 2 is a cross-sectional elevation view of an acoustic transducer panel in accordance with one embodiment of the invention;

Figure 3 is a perspective view of a ceramic preform useful for fabricating the acoustic transducer panels illustrated in Figures 2 and 9;

Figures 4 - 9 are cross-sectional elevation views illustrating steps in the fabrication of an acoustic trans-



ducer panel in accordance with another embodiment of the invention, the completed transducer panel being shown in Figure 9;

5 Figure 10 is a cross-sectional elevation view of an acoustic transducer panel in accordance with yet another embodiment of the invention;

Figure 11 is a cross-sectional elevation view of an acoustic transducer panel in accordance with still another embodiment of the invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 The composite acoustic transducer panel described below is an improvement of the typical prior art transducer panel illustrated in Figure 1. Figure 1 shows a cross section of  
15 prior art composite transducer panel 10 in which rods or elements 12 of a piezoelectric or electrostrictive ceramic material, e.g., PZT are arranged in an array and are encapsulated in soft polymeric matrix 14, e.g., a soft polyurethane including voids 16, i.e., minute hollow polymeric  
20 spheres, to form composite body 18. A similar composite body and its fabrication are described in further detail in Patent 5,340,510, referenced above. Stiff GRP face plates 20 are bonded to opposite face surfaces 22 of composite body 18 by layers 24 of a conductive adhesive, e.g., a conductive  
25 epoxy adhesive, to enhance uniform plane-front surface displacement at the surface of transducer panel 10. However, they also prevent transducer panel 10 from being bendable, conformable, or conformal to other surfaces, e.g., non-planar surfaces. Additionally, bonding of face plates  
30 20 to composite body 18 with adhesive layers 24 may render the devices susceptible to shock damage. Clearly, for some applications such as large-area, underwater, and shock-prone applications, a more rugged and conformable design is required.

The composite transducer panels in accordance with the invention eliminate the need for separate, adhesively bonded face plates of the prior art panel illustrated in Figure 1. Instead, the novel transducer panel includes integral polymer face plates or a voided conformable matrix, each described in further detail below. In the embodiments including the conformable matrix a specifically defined voided, stiff matrix phase completely encapsulates the PZT rods, while in the embodiments utilizing the integral face plates a stiff matrix material partially encapsulates the rods at the opposite faces of the composite panel but does not contact the rod side surfaces at the center of the panel.

The descriptions below of various illustrative embodiments shown in the Drawings is not intended to limit the scope of the present invention, but merely to be illustrative and representative thereof.

Turning now to Figure 2, composite acoustic transducer panel 30 in accordance with one embodiment of the invention includes rods or elements 32 of a piezoelectric or electrostrictive ceramic material, e.g., PZT arranged in an array typical of prior art 1-3 composites. Rods 32 are encapsulated in conformable stiff polymeric matrix 34 to form composite body 36. Rods 32 may be provided by any known method for fabricating 1-3 composites, for example that described in Patent 5,340,510, referenced above. Conformable stiff matrix 34 is fabricated from a hard polymeric material such as epoxy or hard polyurethane, preferably one having a hardness of at least 70 shore D. Voids (not shown) are homogeneously distributed throughout matrix 34 in an amount of about 1 - 50, preferably 5 - 25 volume %. The voids may be provided by, e.g., minute hollow polymeric spheres or other filler materials. The voided hard polymeric material is cast over a 1-3 preform in a mold. The 1-3 preform is shown in Figure 3 and is described below and

in Patent 5,340,510. Upper face 38 and lower face 40 of composite body 36 may be ground to expose rod ends 42 and 44. Electrodes 46 and 48 are applied to upper and lower faces 38 and 40, respectively, to contact rod ends 42 and 44 to provide electrically activatable transducer panel 30. This device can be rendered conformable to non-planar mounting surfaces by the application of heat and pressure. The voids distributed throughout the stiff matrix lower the density of the matrix and reduce acoustic decoupling between the PZT ceramic elements. The device is stronger than prior art transducer panels, resisting delamination, because the matrix material bonds well to the sides of the ceramic rods. If desired, the electroded upper and lower surfaces may be protected, EMI shielded, and/or further strengthened by applying or casting a further layer of the voided stiff material used for the matrix or by bonding on stiff cover plates of, e.g., GRP or metal or flexible circuit board material.

Figure 3 shows a photograph of a typical 1-3 densified preform, for example, one injection molded in accordance with the process described in Patent 5,340,510, referenced above. This preform may be used to fabricate the transducer panel of Figure 2 or any of the transducer panels described below. The preform includes a planar ceramic base with a plurality of ceramic rods or elements extending normal to the base in a regular array. A typical size for such a preform is about 50 mm x 50 mm with rods or elements 0.2 - 2 mm in diameter and having an aspect ratio (length to diameter) of about 3:1 to about 20:1. Although injection molding is preferred for fabrication of the preform, other methods may be used, e.g., slip casting or dicing, as described in Patent 5,340,510. The ceramic is a piezoelectric or electrostrictive material, e.g., a lead zirconate titanate (PZT), lead magnesium niobate (PMN), or similar materi-

als, as described in Patent 5,340,510. The preferred pre-  
form has been densified by known means, e.g., sintering, to  
a density of at least about 95%, preferably at least about  
97%, of theoretical density. For the fabrication method  
described herein, a densified preform having a base inter-  
connecting the rods is preferred. Several densified pre-  
forms may be arranged edge to edge in a planar encapsulation  
mold of a size selected to fabricate a panel of the desired  
size. The combined preforms then form an array of rods or  
elements larger than the size of each individual preform.  
The appropriate encapsulating material is then cast over the  
array of rods in the mold to form the composite body.  
Alternatively, a single preform may be placed in an appro-  
priately sized encapsulation mold and the encapsulating  
material cast over the preform to form the composite body.

Figures 4 - 9 illustrate the fabrication of a composite  
acoustic transducer panel in accordance with another embodi-  
ment of the invention. Figure 9 shows the completed con-  
formable composite transducer panel 50 including rods or  
elements 52 of a piezoelectric or electrostrictive ceramic  
material, e.g., PZT arranged in an array typical of prior  
art 1-3 composites, e.g., that array shown in Figure 3.  
Rods 52 are partially encapsulated at their upper ends 54 in  
stiff polymeric upper integral face plate 56 and at their  
lower ends 58 in stiff polymeric lower integral face plate  
60 to form composite body 62. As used herein, the term  
"face plate" is intended to mean a stiff plate at one face  
of the composite body which serves to provide more uniform  
plane-front surface displacement at the surface of the body.  
However, the "integral" face plates described herein are  
stiff plates which are molded or otherwise fabricated to be  
a part of (integral with) a composite body, not merely end  
caps or cover plates bonded to the ends of the ceramic ele-  
ments with adhesive layers as in the prior art face plates.

5 In this embodiment, each integral face plate provides a stiff partial matrix surrounding rod ends 54 or 58. Typical materials for integral face plates 56 and 60 include, e.g., hard polyurethanes, epoxy resins, and thermoplastic resins. Upper and lower faces 64 of composite body 62 are ground to expose rod ends 54 and 58. Thin upper and lower electrodes 66, e.g., of vapor deposited or screen printed metal, applied at upper and lower faces 64 electrically contact rod ends 54 and 58 to provide electrically activatable transducer panel 50.

10 Hard polymeric edge strips at all four edges of composite body 62 (only edge strip 68 is shown for clarity) provide stability to the body and cooperate with integral face plates 56 and 60 to enclose air gap 70 within composite body 62. Preferably, the polymer of edge strip 68 is the same as that of integral face plates 56 and 60. Optionally, transducer panel 50 may be rendered waterproof before use by encapsulation, e.g., in polyurethane jacket 72.

15 Typical steps in the fabrication of this transducer panel are illustrated in Figures 4 - 9. Figure 4 shows several densified preforms 74, e.g., several of the preforms shown in Figure 3, arranged edge to edge in planar encapsulation mold 76 of a size selected to fabricate a panel of the desired size. (In Figures 4 - 7, the preforms are shown in simplified form for clarity of illustration.) The combined preforms then form an array of rods or elements 52 larger than the size of each individual preform 74. Alternatively, the subsequent steps of the method may be carried out on a single preform 74 in an appropriately sized encapsulation mold.

20 The coplanar array of preforms 74 is then partially encapsulated in encapsulation mold 76, as shown in Figure 5. Polymeric encapsulant 84 is cast in mold 76, e.g., as a melt or liquid, flowing into troughs 82 to depth 86 above bases

80 to partially encapsulate rods 52 at ends 54 adjacent bases 80, leaving opposite rod ends 58 free, and forming partial composite structure 88. A typical depth 86 is, e.g., 1 - 2 mm. Encapsulant 84 is selected to be castable but to be rigid after curing. Typical encapsulants 84 are hard polyurethanes and epoxy resins. Optionally, for some applications, encapsulant 84 may include voids, particles, or other fillers (not shown). For example, minute hollow polymeric spheres may be dispersed throughout encapsulant 84 to decrease the weight of the transducer. Alternatively, encapsulant 84 may be made electrically conductive, e.g., by the addition of a conducting material such as metal particles or carbon, so as to function as an electrode. In another alternative, a dense particulate additive material, e.g., steel, lead, tungsten, etc., may be incorporated into encapsulant 84 to increase the mass of the integral face plate, for the purpose of reducing the transducer resonant frequency.

After curing of encapsulant 84, partial composite structure 88 is inverted in mold 76, as shown in Figure 6, with free rod ends 58 resting on the mold and bases 80 forming a top surface 90. An additional amount of encapsulant 84 is cast in mold 76 to fill the open ends of troughs 82 to depth 92, partially encapsulating rods 52 at ends 58. Preferably, depth 92 is approximately equal to depth 86. Both depth 86 and depth 92, however, are selected to leave air gap 70 between layers of encapsulant 84.

After curing of the additional encapsulant 84, composite body blank 94 is removed from mold 76, as shown in Figure 7, and hard polymeric edge strips 68 are cast in a separate operation. Only one edge strip 68 is shown in the Figure, but all edges of blank 94 are filled with edge strips 68 to enclose air gap 70. In most embodiments, it is preferred that the polymer of edge strip 68 is the same as

that of encapsulant 84. An exception to this preference is an embodiment in which encapsulant 84 is a conducting material, in which case an electrically insulating material is selected for edge strip 68 to avoid shorting of the electrodes.

Composite body blank 94 is then machined to remove bases 80 and to expose ends 54 and 58 of rods 52 at planar faces 64 to form composite body 62, shown in Figure 8. Thus cured, machined encapsulant 84 forms integral face plates 56 and 60 at rod ends 54 and 58, respectively. Composite body 62 includes rods 52, integral face plate 56 fixing the rods in their array at rod ends 54, integral face plate 60 fixing the rods at rod ends 58, edge strips 68 around all edges of composite body 62, and enclosed air gap 70. Rod ends 54 and 58 are exposed at upper and lower faces 64 and air gap 70 is completely enclosed by face plates 56 and 60, rods 52, and edge strips 68.

To complete transducer panel 50, electrodes 66, for example screen printed silver epoxy or vapor deposited gold electrodes, are applied to faces 64, as shown in Figure 9. Optionally, after wiring by conventional means (not shown), the entire transducer panel 50 is then encapsulated in jacket 72. (Optionally, a jacket similar to jacket 72 may be provided to encapsulate transducer panel 30 of Figure 2.)

Yet another embodiment is illustrated in Figure 10. In Figure 10, like features to those shown in Figures 4 - 9 are indicated by the same reference numerals. Conformable composite body 62 with electrodes 66 deposited thereon is further improved by flexible circuit boards 96 applied on either side of the electroded composite body and bonded to electrodes 66. Any conventional circuit board material may be used. Optionally, the circuit board conductor can be patterned by conventional means to allow selected areas of the composite to be connected electrically as individual

elements of an array. The circuit board layers provide a strong and rugged device without significant reduction in its conformability because of the flexible nature of the circuit board material. Flexible circuit boards 96 can also  
5 be adapted in known manner to provide EMI shielding for the device. A preferred material for flexible circuit boards 96 is a polyimide material plated on both sides with copper conductors.

In an alternate embodiment, separate areas of the  
10 transducer panel provide regions, each including one or more elements, and separate upper and lower electrodes are provided for each region to electrically contact the elements within that region. The above-described flexible circuit boards may then be adapted to provide separate electrical  
15 contacts to each of these separate electrodes so that the elements in each region may be activated independently of the elements in other regions.

Still another embodiment is illustrated in Figure 11. In Figure 11, like features to those shown in Figures 4 - 9  
20 are indicated by the same reference numerals. Conformable composite transducer panel 100 includes PZT rods 52 arranged in a 1-3 array and partially encapsulated at their upper and lower ends 54 and 58 in hard polymeric upper and lower integral face plates 56 and 60, as described above. Hard poly-  
25 meric edge strips 68 enclose the gaps between integral face plates 56 and 60, also as described above.

However, rather than air gaps 70 as shown in Figures 9 and 10, the space enclosed by rods 52, integral face plates 56 and 60, and edge strips 68 is filled with soft polymeric  
30 layer 102 to form composite body 104. In one embodiment of the method described herein, soft polymeric layer 102 may be cast from a soft polymeric material after the casting of upper integral face plate 56 (Figure 5). After curing of soft polymeric layer 102, partial composite body 88 need not



be inverted in the mold for casting of lower integral face plate 60 (Figure 9), since no space is required between the integral face plates and the soft polymeric layer. Lower integral face plate 60 may be cast directly over soft polymeric layer 102. Typically, soft polymeric layer 102 is compressible and/or includes voids (not shown), e.g., minute hollow polymeric spheres. The preferred material for layer 102 is a voided soft polyurethane or rubber, although other suitable soft polymeric materials may be selected empirically with minimal experimentation. Thin upper and lower electrodes 66 are applied at upper and lower faces 64 to electrically contact the ends of rods 52, as described above, to provide electrically activatable transducer panel 100. Optionally, transducer panel 100 may be encapsulated in a jacket similar to jacket 72, also described above. Also optionally, soft polymeric layer 102 may extend out to the edges of face plates 56 and 60, and edge strips 68 may be omitted.

In other embodiments of the method described herein, soft polymeric layer 102 (as described above and shown in Figure 11) is cast before the casting of encapsulant 84 which forms upper and lower integral face plates 56 and 60. In one embodiment, a soft polymeric material is molded to cover one end of each of rods 52, leaving the opposite ends unencapsulated. The soft polymer typically is the same type of soft polymer used to form the above-described soft polymeric layer shown in Figure 11. For example, the soft polymer may be compressible and/or may include voids, e.g., minute hollow polymeric spheres. The preferred soft polymeric material is a voided soft polyurethane or rubber, although other suitable soft polymeric materials may be selected empirically with minimal experimentation. The soft polymer is cured and the ceramic base is removed. Then, the cured soft polymer is partially removed by, e.g., abrading

or dissolving away the excess material to, e.g., depth 92 (Figure 6) to form a layer similar to soft polymeric layer 102. The rod ends are exposed at both upper and lower body faces 64 so that they extend outward from or "stand proud" above and below opposite surfaces of the soft polymeric layer. In an alternate method, a layer of a sacrificial material, e.g., a dissolvable or meltable wax is cast to form a layer encapsulating one end of the rods, e.g., to depth 86 (Figure 5) leaving the opposite end of the rods unencapsulated. The soft polymeric layer is then cast leaving the rod ends exposed, e.g., to depth 92. Removal of the ceramic base and the sacrificial layer leaves the rods exposed at both ends. In either of these embodiments, encapsulant 84 is then cast to form the upper and lower integral face plates encapsulating the ends of rods 52 and forming composite body 104. If desired, edge strips may also be cast from encapsulant 84, as described above. The transducer panel is then completed as described above with reference to Figure 11.

The piezoelectric or electrostrictive ceramic elements described with regard to Figures 2 - 11 are cylindrical rods. Alternatively, the elements may be rectangular, hexagonal, or any shape conventional for the above-described 1-3 composites. Also alternatively, the composite may be a 2-2 composite having thin, rectangular elements embedded in a conformable stiff polymeric matrix or in stiff polymeric integral face plates, with or without air gaps, in a manner similar to that described above for the 1-3 composites. As an alternative to PZT, the rods or elements may be fabricated from another piezoelectric or electrostrictive ceramic material, for example, a lead zirconate titanate (PZT), lead magnesium niobate (PMN), barium titanate (BT), lead titanate (LT), or similar materials, as described in Patent 5,340,510. In an alternative fabrication method, the ele-

ments may be pressed into the material of the integral face plate while it is in a softened state.

5       The invention described herein presents to the art novel, improved composite transducer panels which are stronger and more rugged than prior art composite transducer panels. The panels can be conformed to the mounting platform and exhibit high response levels in hydrostatic sensing and actuation applications.

10       While there has been shown and described what are at present considered the preferred embodiments of the invention, it will be apparent to those skilled in the art that modifications and changes can be made therein without departing from the scope of the present invention as defined by the appended Claims.

WE CLAIM:

1. A conformable composite acoustic transducer panel comprising a conformable composite body having upper and lower planar faces and upper and lower thin, flexible electrodes bonded to said upper and lower faces, respectively,  
5 said composite body comprising:

an array of individual piezoelectric or electrostrictive ceramic elements, each of said elements having opposing ends and one or more sides interconnecting said opposing ends, said elements being  
10 disposed normal to said upper and lower faces and extending through said composite body from said upper face to said lower face to electrically contact each of said electrodes; and

a matrix of conformable, stiff, voided material comprising a hard polymeric material and about 1 - 50  
15 volume percent voids, and wherein said voided material extends the full depth of said composite body and is bonded to each of said elements over the full length of each of said element sides, and  
20 upper and lower surfaces of said matrix are coplanar with upper and lower ends, respectively, of said elements to provide said upper and lower faces, respectively.

2. A transducer panel in accordance with claim 1 wherein said element ends are exposed at at least one of said upper and lower faces to contact said electrodes.

3. A transducer panel in accordance with claim 1 or 2 wherein said upper and lower surfaces of said matrix are coplanar with said element ends to provide said upper and lower faces.

4. A method of fabricating a conformable composite acoustic transducer panel comprising a conformable composite body having upper and lower planar faces, said method comprising:

5 placing in a mold a ceramic body comprising an array of individual piezoelectric or electrostrictive ceramic elements, each of said elements having opposing first and second ends and one or more sides interconnecting said first and second ends;  
10 encapsulating in a polymer said ceramic body within said mold to the full depth of said ceramic body to form on curing of said polymer an encapsulated ceramic body, wherein said polymer is a conformable, stiff, voided polymer comprising a hard  
15 polymeric material and about 1 - 50 volume percent voids and said polymer bonds to said element sides, and producing said conformable composite ceramic body, outer surfaces of said matrix providing said upper and lower planar faces of said  
20 conformable composite body.

5. A method in accordance with claim 4 wherein:  
said ceramic body further comprises a base, said elements being disposed normal to said base with said first ends fixed thereto, said placement of said  
5 ceramic body in said mold including resting said ceramic body on its base within said mold, and said encapsulating of said elements including disposing said polymer over said ceramic body within said mold;  
10 said polymer is disposed over said ceramic body to encapsulate said base and said elements to form said encapsulated ceramic body;

said method further comprising:

15        machining said encapsulated ceramic body to remove said  
         base and expose said first and second element  
         ends, producing said conformable composite ceramic  
         body, outer surfaces of said matrix providing said  
         upper and lower planar faces of said conformable  
         composite body.

6.     A method in accordance with claim 4 or 5 further  
comprising the step of applying first and second thin, flex-  
ible electrodes to said upper and lower planar faces, re-  
spectively, of said conformable composite body to bond said  
5       first and second electrodes thereto to form said transducer  
      panel.

7.     A conformable composite acoustic transducer panel  
comprising a conformable composite body having upper and  
lower planar faces and upper and lower thin, flexible elec-  
trodes bonded to said upper and lower faces, respectively,  
5       said composite body comprising:

         an array of individual piezoelectric or electrostric-  
         tive ceramic elements, each of said elements hav-  
         ing opposing ends and one or more sides intercon-  
         necting said opposing ends, said elements being  
10       disposed normal to said upper and lower faces and  
         extending through said composite body from said  
         upper face to said lower face to electrically  
         contact each of said electrodes; and

         an upper integral face plate and a lower integral face  
15       plate spaced apart from one another, each of said  
         integral face plates extending through only a  
         portion of the depth of said composite body and  
         being bonded to each of said elements over only a  
         portion of each of said element sides, the outer

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planar surfaces of said upper and lower integral face plates being coplanar with upper and lower ends, respectively, of said elements to provide said upper and lower faces, respectively.

8. A transducer panel in accordance with claim 7 wherein said element ends are exposed at at least one of said upper and lower faces to contact said electrodes.

9. A transducer panel in accordance with claim 7 or 8 wherein said outer planar surfaces of said integral face plates are coplanar with said element ends to provide said upper and lower faces.

5

10. A transducer panel in accordance with any one of claims 7 - 9 wherein said upper and lower integral face plates are spaced apart from one another, providing an air gap therebetween, all side edges of said upper and lower integral face plates being joined by edge strips to completely enclose said air gap.

5

11. A transducer panel in accordance with any one of claims 7 - 9 wherein said upper and lower integral face plates are spaced apart from one another, providing a space therebetween, said space being filled with a soft, compressible polymeric material.

12. A transducer panel in accordance with any one of claims 7 - 11 further comprising a flexible circuit board bonded to each of said electrodes to provide EMI shielding to said transducer panel.

13. A transducer panel in accordance with any one of claims 7 - 12 wherein said integral face plates include sufficient dense particulate material to increase the mass of said integral face plates and to reduce the resonant frequency of said transducer panel.

14. A transducer panel in accordance with any one of claims 7 - 13 wherein each of at least two regions of said panel includes one or more of said elements, separate electrodes being provided for each region at said upper and lower planar surfaces to electrically contact those of said elements within that region, and wherein a flexible upper circuit board provides a separate electrical contact to each of said upper electrodes and a flexible lower circuit board provides a separate electrical contact to each of said lower electrodes, such that those of said elements in each region may be activated independently of those of said elements in other regions.

15. A method of fabricating a conformable composite acoustic transducer panel comprising a conformable composite body having upper and lower planar faces, said method comprising:

placing in a mold a ceramic body comprising an array of individual piezoelectric or electrostrictive ceramic elements, each of said elements having opposing first and second ends and one or more sides interconnecting said first and second ends;

encapsulating in a polymer a portion of each of said element sides adjacent said first element ends to a first depth within said mold, leaving a portion of each of said element sides unencapsulated to form a partially encapsulated ceramic body, said polymer being selected to provide on curing a



first stiff polymeric integral face plate bonded to said portion of said element sides adjacent said first element ends;

inverting said partially encapsulated ceramic body in said mold;

encapsulating in said polymer a portion of each of said element sides adjacent said second element ends to a second depth within said mold, leaving a portion of each of said element sides unencapsulated to form on curing of said polymer an encapsulated ceramic body having a first stiff polymeric integral face plate bonded to said portion of said element sides adjacent said first element ends, a second stiff polymeric integral face plate bonded to said portion of said element sides adjacent said second element ends, and a gap between said integral face plates, producing said conformable composite ceramic body, outer surfaces of said first and second integral face plates providing said upper and lower planar faces of said conformable composite body.

16. A method in accordance with claim 15 wherein: said ceramic body includes a base, said elements being disposed normal to said base with said first ends fixed thereto, said placement of said ceramic body in said mold including resting said ceramic body on its base within said mold;

said polymer is disposed over said ceramic body to said first depth encapsulating said base and a portion of each of said element sides adjacent said first element ends to form a partially encapsulated ceramic body;

said partially encapsulated ceramic body is inverted  
such that said base and said first integral face  
plate are supported in said mold by said unencap-  
sulated portion of said elements;  
said method further comprising:  
machining said encapsulated ceramic body to remove said  
base and expose said first and second element  
ends, producing said conformable composite ceramic  
body, outer surfaces of said first and second  
integral face plates providing said upper and  
lower planar faces of said conformable composite  
body.

17. A method in accordance with claim 15 or 16 further  
comprising the step of applying a stiff polymeric edge  
joining means to said encapsulated body to join said first  
and second integral face plates at their outer edges and  
enclose said gap.

18. A method in accordance with any one of claims  
15 - 17 further comprising the step of applying upper and  
lower thin, flexible electrodes to said upper and lower  
planar faces, respectively, of said conformable composite  
body to bond said first and second electrodes thereto to  
form said transducer panel.

19. A method in accordance with any one of claims  
15 - 18 further comprising the step of:  
bonding a flexible circuit board to each of said elec-  
trodes, each of said circuit boards providing  
electrical contact to its respective one of said  
electrodes and EMI shielding to said transducer  
panel.

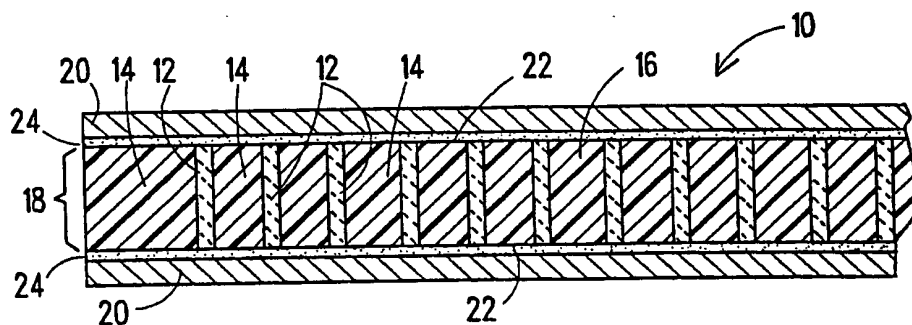
20. A method in accordance with any one of claims  
15 - 17 further comprising the steps of:

5       bonding upper and lower thin, flexible electrodes to  
          the portions of said upper and lower planar faces  
          in each of at least two regions of said panel,  
          each of said regions including one or more of said  
          elements, to electrically contact only those of  
          said elements within that region;

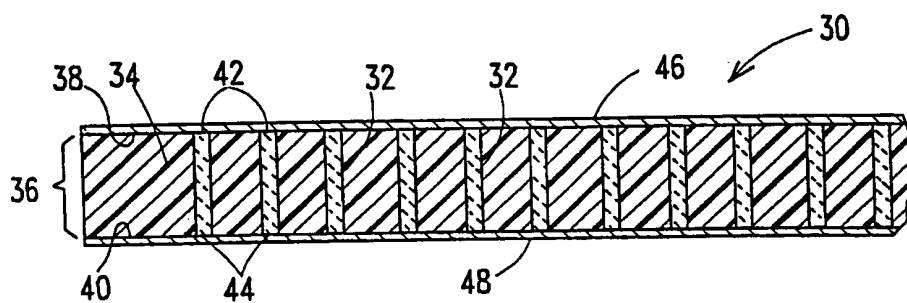
10       bonding a flexible upper circuit board to said upper  
          electrode, said upper circuit board providing a  
          separate electrical contact to each of said upper  
          electrodes; and

15       bonding a flexible lower circuit board to said lower  
          electrode, said lower circuit board providing a  
          separate electrical contact to each of said sepa-  
          rate lower electrodes, such that those of said  
          elements in each region may be activated indepen-  
          dently of those of said elements in other regions.

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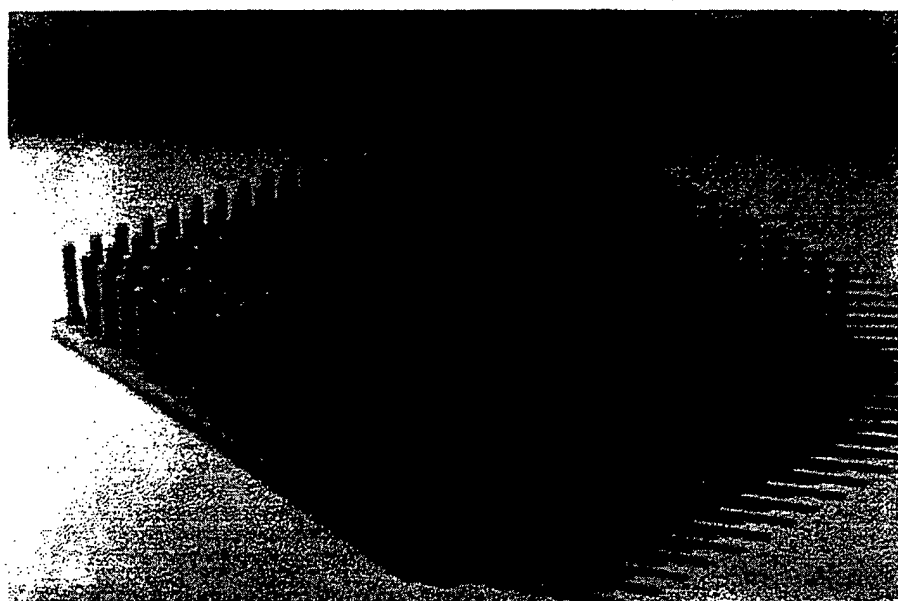


**FIG. 1**  
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**FIG. 2**

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*FIG. 3*

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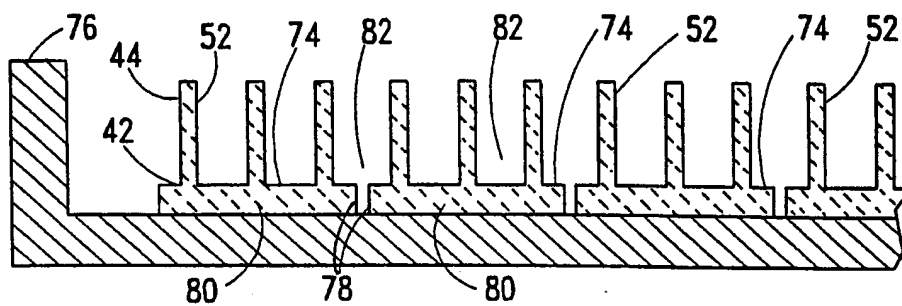


FIG. 4

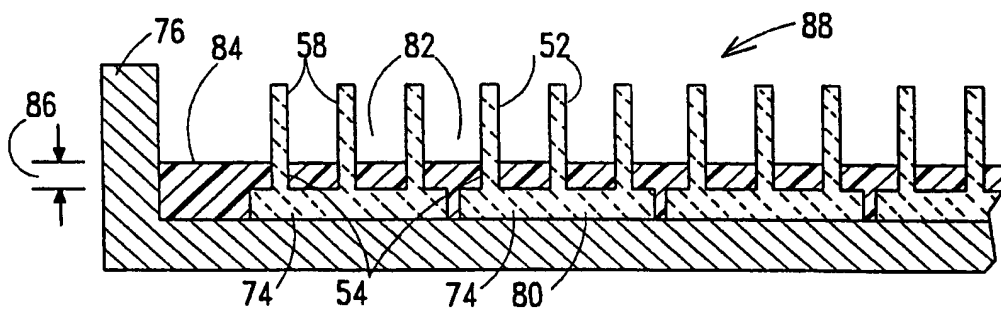


FIG. 5

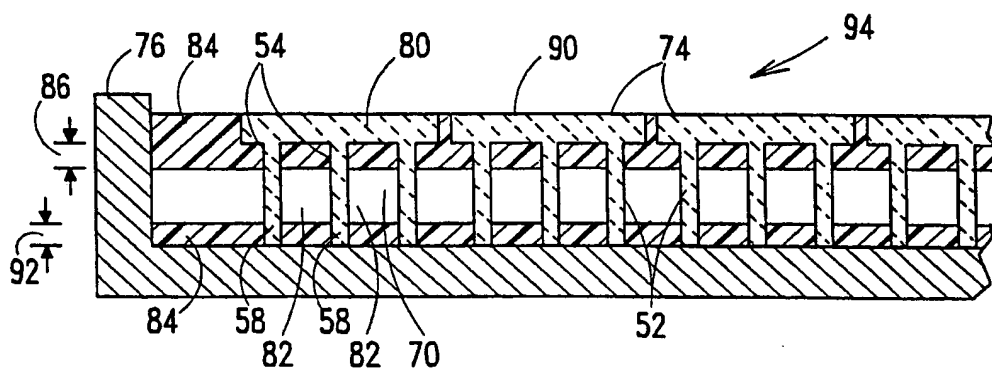


FIG. 6

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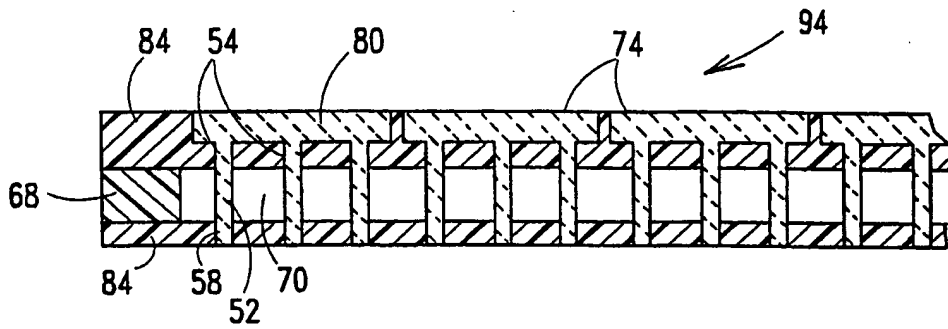


FIG. 7

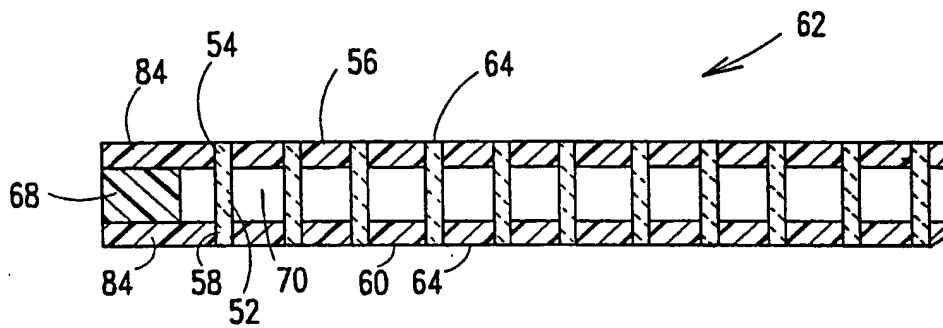


FIG. 8

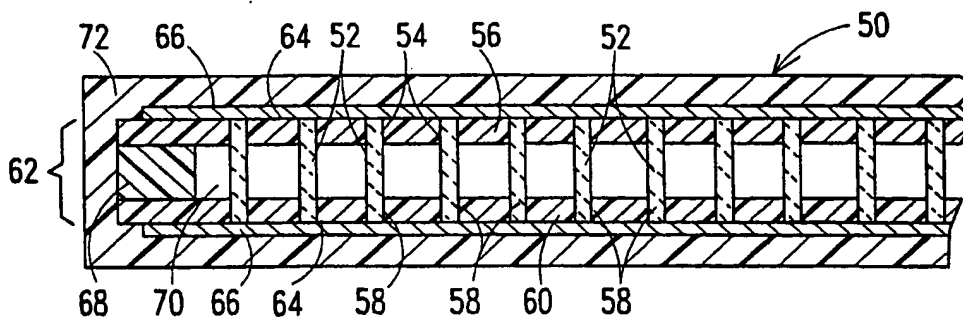


FIG. 9

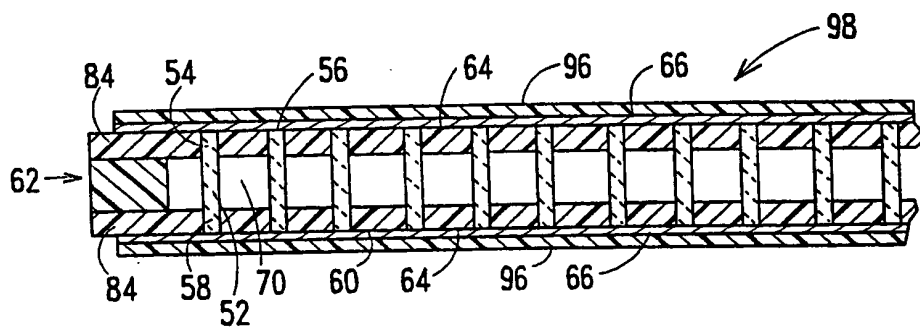


FIG. 10

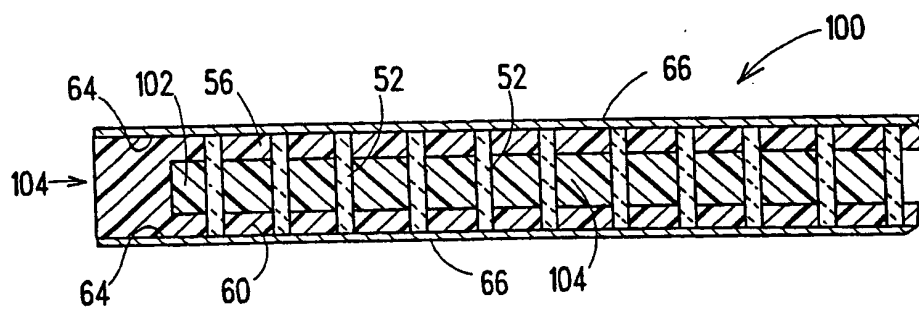


FIG. 11